SIMULATION OF BUBBLES RISE IN CAVITY USING LATTICE BOLZTMANN METHOD

WAN MOHAMAD DASUQI BIN WAN MA'SOR

Report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature:
Name of Supervisor: MUHAMAD ZUHAIRI BIN SULAIMAN
Position: LECTURER
Date: 6/12/2010

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature:
Name: WAN MOHAMAD DASUQI B WAN MA'SOR
Id Number: MA07052
Date: 6/12/2010

ACKNOWLEDGEMENTS

First of all, I would like to express my heartily gratitude to my research supervisor, Associate Mr. Muhamad Zuhairi bin Sulaiman for his guidance, advices, efforts, supervision and enthusiasm given throughout for the progress of this research.

In preparing this thesis, I was in contact with many people, lecturers, and training engineers. They have contributed towards my understanding and thoughts. Without their continued support and interest, this thesis would not have been the same as presented here.

I would like to express my sincere appreciation to my parents for their support to me all this year. Without them, I would not be able to complete this research. Besides that, I would like to thank my course mates and my friends especially my section M06 for their help, assistance and support and encouragement.

ABSTRACT

This thesis explains the simulation of bubbles rise in cavity using Lattice Boltzmann Method. The two phase bubbles simulated using Lattice Boltzmann Equation. The simulation was done on two dimensional only and multiple bubbles motion under buoyancy was carried out. Three configurations of the bubble simulation was being simulated using LBM code development. Free energy model was reviewed and the base on isotropy approach (Yonetsu Approach) used and Galilean invariance are also considered. Three variations of configuration used which are distance between bubbles, configuration base on differential of Eotvos number, and configuration base on different Kappa number. The result obtained from simulation is proven by lattice Boltzmann method which to be used for multiphase. Simulation results are validated and has good agreement with previous studies. The experimental setup for bubble rise was-fabricated and due to some limitations, results obtained are not well satisfied.

ABSTRAK

Thesis ini menerangkan mengenai kajian terhadap simulasi buih yang naik dari kaviti melalui aliran dua fasa berdasarkan kaedah Lattice Boltzmann. Simulasi buih ini berasaskan dari persamaan kaedah Lattice Boltzmann. Simulasi ini hanya dilakukan dalam dua dimensi analisis sahaja dan pada masa yang sama apungan ke atas pergerakan buih berganda akan dapat dipelajari. Tiga jenis rupa bentuk simulasi buih yang menggunakan LBM akan di simulasikan melalui perisian Visual C++. Model tenaga bebas akan di tinjau kembali berdasarkan model yang terbaru yang berasas pendekatan isotropik(Pendekatan Yonetsu). Ketidaksamaan Galliean juga akan di pertimbangkan. Rupa bentuk yang disimulasikan di dalam thesis ini antaranya adalah rupa bentuk disebabkan pendekatan jarak diantara buih, rupa bentuk yang disebabkan perbezaan nombor Eotvos, dan terakhir sekali disebabkan perbezaan nombor Kappa. Keputusan yang diperolehi melalui simulasi ini telah dibuktikan melalui persamaan Lattice Boltzmann dan digunakan untuk dua fasa. Keputusan simulasi ini di perakui sah dan mendapat persetujuan yang baik dengan pembelajaran sebelum ini. Eksperimen penaikan buih secara manual juga telah dicipta dan bergantung ke atas tahap yang terhad, keputusan yang diperolehi masih belum sempurna.

TABLE OF CONTENT

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CFD	-	Computational Fluid Dynamic
$f^{(i)}$	-	Distribution function
$\boldsymbol{p}$	-	Pressure (pa)
$\boldsymbol{F}$	-	Force (N)
Eo	-	Eotvos number Dimensionless
Re	-	Reynolds number Dimensionless
Mo	-	Morton number Dimensionless
σ	-	Surface tension Dimensionless
κ	-	Density gradient/kappa Dimensionless
D2Q9	-	Direction of bubbles Dimensionless
$\boldsymbol{u}$	-	Velocity Dimensionless
f_{eq}	-	Equilibrium distribution function
ρ	-	Density of phase Dimensionless
υ	-	Kinematic shear viscosity Dimensionless
LBM	-	Lattice Boltzmann Method
ρ_L	-	Density of liquid phase Dimensionless
ρ_G	-	Density of gases phase Dimensionless
g	-	Gravity acceleration Dimensionless
d	-	Diameter of bubbles Dimensionless

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the research of simulation bubbles rise in cavity using lattice Boltzmann method, the basic theory of Lattice Boltzmann was used. The basic Lattice Boltzmann equation was extracted to dimensionless equation that was found by several approach of simulation bubbles rise. The approach simplify the equation for easy to read by computational. The important of simulation is the result obtain must be according to the basic theory that is the Lattice Boltzmann Method, LBM.

1.2 Background of Lattice Boltzmann Method

The lattice Boltzmann method (LBM) has been proposed as a mesoscopic approach to the numerical simulations of fluid motion on the statistical-thermodynamic assumption that a fluid consist of many virtual particles repeating collision and translation through which their velocities distributions converge to a state of local equilibrium. Lattice Boltzmann method, based on the lattices gas cellular automaton, possesses the advantages such as relatively easy implementation of boundary conditions on complicated geometry, high efficiency on parallel processing, and flexible reproduction of interface between multiple phases. The last point on which we focus in this study arises from the introduction of repulsive interaction between particles without any boundary condition for interface. As a result, LBM is more useful than other conventional methods for the numerical analysis of multiphase fluid system, where the flow pattern changes not only spatially but also temporally due to deformation, break up, and coalescence of droplet or bubbles (Orszag SA, 1995). Therefore its apply LBM to simulations of two-phase fluid motion. The low and high-density fluids in this study, referred to as bubble and liquid respectively, correspond to the pressurized fluids having a small density ratio such as steam and water in PWR nuclear power plants. Another advantage of LBM occurs on implementation of complicated boundary conditions to be seen in fuel assemblies, although the topic is not discussed in detail in this study. Lattice Boltzmann method therefore is a promising method suitable for simulating fluid flows in nuclear engineering.

In single-phase LBM, there have already been a lot of numerical results for incompressible viscous fluid flows. On the other hand, several kinds of multiphase fluid model have recently been proposed and applied to the simulations of phase separation and transition. The first immiscible multiphase model reproduced the phase separation by the repulsive interaction based on the color gradient and the color momentum between red-and-blue-colored particles representing two kinds of fluid. Shan and Chen proposed the gas-liquid model applicable to the phase transition with the potential between particles, while another gas-liquid model proposed by Swift. Simulates phase transitions consistent with the thermodynamics on the theory of Van de Waals-Chan-Hillard free energy.

(Kato, 2001) also presented a two phase model with a pseudo potential for van de Waals fluids. Lattice Boltzmann method was used to simulate the condensation of liquid droplets in supersaturated vapor, the two-phase fluid flow through sandstone in three dimensions and so on. However, it has not been applied to any quantitative numerical analysis of the motion of bubbles or droplet in two-phase flows under gravity in two and three dimensions, because the main purpose in previous works was to develop multiphase model and examine its property, or to reproduce fundamental phenomena in multiphase fluid where buoyancy effect is negligible.

Therefore, in LBM, we consider the buoyancy effect due to density difference in two phase fluid characterized with the non-dimensional numbers such as Eotvos and Morton numbers, and develop the three-dimensional version of the binary fluid model which is a newest one proposed by (Swift, 2001). This model using the free-energy approach has one important improvement that the equilibrium distribution of fluid particles can be consistently based on thermodynamics, compared with other models which are based on phenomenological models of interface dynamics. Consequently, the total energy, including the surface energy, kinetic energy, and internal energy can be conserved. Furthermore, it also reproduces Galilean invariance more properly than one-component fluid model.

Multiphase flow of fluids can be found everywhere either in natural environment phenomenon or in the technology evolution. Study of multiphase flow could contribute a better understanding on multiphase behavior. The knowledge of multiphase flow behavior is important in the development of equipment which directly related to multiphase problem. Lattice Boltzmann Method (LBM) is relatively new method and has a good potential to compete with traditional CFD methods. Recently it has been proved to be a promising tool to simulate the viscous flow (S. Chen and G. Doolen, 1998).

LBM base on derivation of kinetic theory which working in mesoscopic level instead of macroscopic discretization by traditional method. Instead of easy in incorporating with microscopic physics, it is also having shorter time compare to the current method. LBM have more advantages in multi-phase compare to traditional method.

In multi-phase, two main issues which are surface tension force modeling and interface recording have to be considered. In this study, we visualise the numerical results of bubble motions using LBM method by AVS Express software. The LBM coding will create by the software Microsoft Visual C++ SP6 and the result of the motion of bubbles will shown by AVS Express software.

1.3 Problem Statement

Bubbles rising simulation is complex via experiment. The buoyancy force is difficult to control in experiment. Derivation of basic Bhanatgar-Gross-Krook(BGK) Collision equation should be derive in macroscopic equation. Simulation by Lattice Boltzmann is not detail as like conventional CFD like VOF.

1.4 Objectives

To predict the bubbles motion under buoyancy force using the lattice Boltzmann method and investigate the bubble behavior of differential configuration of bubbles location. The bubbles also will be investigate by two more cases which is case by Eotvos number, Eo and the other one case by kappa number, κ.

1.5 Project Scopes

The study will perform numerical simulation and modelling base on Lattice Boltzmann Method. Two dimensional (2D) will be considered. Multiple bubbles motion under buoyancy force will be studied numerically. Three cases will be investigated which are simulated;

(i) distance that effect of density interface by variation of Kappa number, κ,
(ii) effect of surface tension by variation of Eotvos number, Eo
(iii) effect of bubbles configuration by variation of distance among bubble.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes a basis of the lattice Boltzmann method and the binary fluid model. The typical LBM discretizes a space uniformly to be isotropic, with hexagonal or square lattice in two dimensions. On such discrete space, a macroscopic fluid is replaced with population of mesoscopic fluid particle with unit mass, which possesses real-value number densities and is allowed to be rest at lattice site or to move with constant velocity set along lattice lines. They repeat two kinds of motion during one time step all over the space, translation from site to site, and elastic collision with each other at each lattice site. The collision is operated statistically according to the rule to conserve mass and momentum of particles, which corresponds to a relaxation process that the distributions of particles approach to a state of local equilibrium. As a result, a macroscopic fluid dynamic in LBM appears emergently from averaging particles motion. All the equation and theory in this chapter became basic to create the simulation of bubbles.

2.2 Lattice Boltzmann Method

The lattice Boltzmann method (LBM) is considerably as an alternatively approach to the well-known finite difference, finite element, and finite volume techniques for according the Navier- Stokes equations. Although as new comer in numerical scheme, the lattice Boltzmann (LB) approach has found recent successes in a host of fluid dynamical problems, including flows in porous media, magneto hydrodynamic, immiscible fluids, and turbulence. LB scheme is a scheme evolved from the improvement of lattice gas automata and inherits some features from its precursor, the LGA. The first LB model was floating- point version of its LGA counterpart each particle in the LGA model (represented by a single – bit Boolean integer) was replaced by a single – particle distribution function in the LB model (represented by floating point number). The lattice structure and the evolution rule remained the same. One important improvement to enhance the computational efficiency has been made for the LB method: the implementation of the BGK approximation (single relaxation time approximation). The uniform lattice structure was unchanged (Lallemand P, 1992).

The starting point in the lattice Boltzmann scheme is by tracking the evolution of the single- particle distribution, f_α. The concept of particle distribution has already well developed in the field of statistical mechanics while discussing the kinetic theory of gases and liquids. The definition implies that the probable number of molecules in a certain volume at certain time made from a huge number of particles in a system that travel freely, without collisions, for distances (mean free path) long compared to their sizes. Once the distribution functions are obtained, the hydrodynamic equations can be derived.

Although LBM approach treats gases and liquids as system consisting of individual particles, the primary goal of this approach is to build a bridge between the microscopic ad macroscopic dynamics, rather than to deal with macroscopic dynamic directly. In other words, the goal is to derive macroscopic equations from microscopic dynamics by means of statistic, rather than to solve macroscopic equation.

The LBM has a number of advantages over other conventional CFD methods. The algorithm is simple and can be implemented with a kernel of just a few hundred lines. The algorithm can also be easily modified to allow for the application for other, more complex simulation components. For example the LBM can be extended to describe the evolution of binary fluid mixtures, r extended to allow for more complex boundary conditions. Thus the LBM is an ideal tool in fluid simulation.

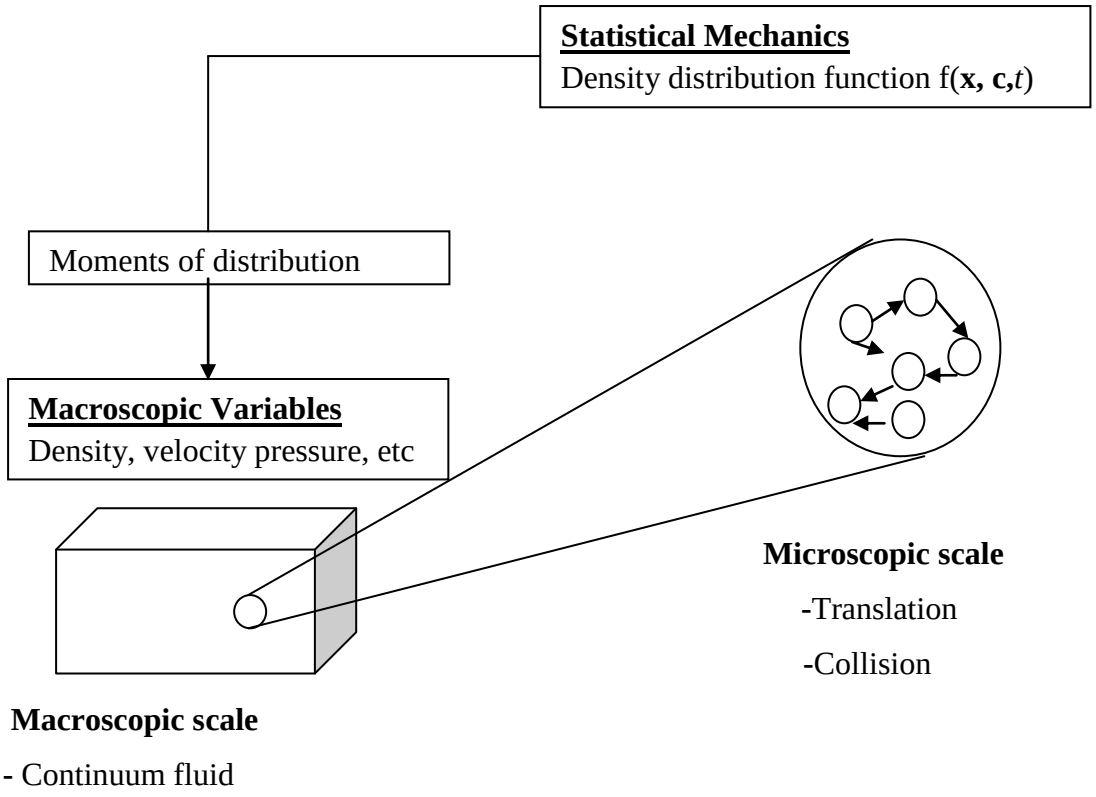

Figure 2.1: General concept of lattice Boltzmann Method

Source: Nor Azwadi Che Sidik, 2007

2.3 Kinetic Theory

Consider a dilute gas consisting of hard spherical particles moving at great velocity (~300 ms^{-1}). We limit their interaction to elastic collisions. Hypothetically, it would be possible to know the position vector (x) and momentum $(\boldsymbol{p})$ of each individual particle at some instant in time. Such information would give the exact dynamical state of the system which, together with classical mechanics, would allow exact prediction of all future states. We could describe the system by a distribution function

$$f^{(N)}(\boldsymbol{x}^{(N)}, \boldsymbol{p}^{(N)}, t) \tag{2.1}$$

where N is the number of particles. Here the distribution is thought of as residing in a 'phase space', which is a space in which the coordinates are given by the position and momentum vectors and the time. Changes in Eq.(2.1) with time are given by the Liouville equation (6N variables). However, this level of description is not possible for real gases, where ~10^{23} (a mole of) particles are involved in just 20 liters of gas at atmospheric temperature and pressure. Fortunately we are usually interested only in low order distribution functions (N = 1, 2)(Orszag SA, 1995).

2.4 First Order Distribution Function

Statistical Mechanics offers a statistical approach in which we represent asystem by an ensemble of many copies. The distribution

$$f^{(1)}(\boldsymbol{x}, \boldsymbol{p}, t) \tag{2.2}$$

gives the probability of finding a particular molecule with a given position and momentum; the positions and moments of the remaining N-1 molecules can remain unspecified because no experiment can distinguish between molecules, so the choice of which molecule does not matter.

This is the 'Single particle' distribution function. $f^{(1)}$ is adequate for describing all gas properties that do not depend on relative positions of molecules (dilute gas with long mean free path).

The probable number of molecules with position coordinates in the range $\mathbf{x} \pm d\mathbf{x}$ and momentum coordinates $\boldsymbol{p} \pm d\boldsymbol{p}$ is given by

$$f^{(1)}(\boldsymbol{x}, \boldsymbol{p}, t) d\boldsymbol{x} d\boldsymbol{p} \tag{2.3}$$

It introduce an external force $\boldsymbol{F}$ that is small relative to intermolecular forces. If there are no collisions, then at time $t + dt$, the new positions of molecules starting at $\boldsymbol{x}$ are

$$\boldsymbol{x} + (\boldsymbol{p}/m)dt = \boldsymbol{x} + (d\boldsymbol{x}/dt)dt = \boldsymbol{x} + d\boldsymbol{x} \tag{2.4}$$

and the new moments are

$$\boldsymbol{p} = \boldsymbol{p} + \boldsymbol{F}dt = p + (d\boldsymbol{p}/dt)dt = \boldsymbol{p} + d\boldsymbol{p}. \tag{2.5}$$

Thus, when the positions and momenta are known at a particular time t, Incrementing them allows us to determine $f^{(1)}$ at a future time $t + dt$:

$$f^{(1)}(\boldsymbol{x} + d\boldsymbol{x}, \boldsymbol{p} + d\boldsymbol{p}, t + dt)\, d\boldsymbol{x} d\boldsymbol{p} = f^{(1)}(\boldsymbol{x}, \boldsymbol{p}, t) d\boldsymbol{x} d\boldsymbol{p} \tag{2.6}$$

This is the streaming process.

There are however collisions that result in some phase points starting at $(\boldsymbol{x}, \boldsymbol{p})$ not arriving at

$$(\boldsymbol{x} + \boldsymbol{p}/m\, dt, \boldsymbol{p} + \boldsymbol{F}\, dt) = (\boldsymbol{x} + d\boldsymbol{x}, \boldsymbol{p} + d\boldsymbol{p}) \tag{2.7}$$

and some not starting at $(\boldsymbol{x}, \boldsymbol{p})$ arriving there too. We set $\Gamma^{(-)} d\boldsymbol{x} d\boldsymbol{p} dt$ equal to the number of molecules that do not arrive in the expected portion of phase space due to